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Power Required to Drive Machine Tools

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THE POWER REQUIRED TO DRIVE MACHINE TOOLS

BY

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THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

VICTOR LORENZO SHELDON

ENTITLED POWER REQUIRED TO DRIVE MACHINE TOOLS

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE DEGREE

OF Bachelor of Science in Mechanical Engineering.

L. P. Breckenridge

HEAD OF DEPARTMENT OF Mechanical Engineering.

INTRODUCTION.

Although the aim in the following pages has been, primarily, to determine the power required to drive various machine tools, it has seemed desirable to give a brief chronological presentation of the subject of dynamometers.

Many of the forms herein briefly described, or referred to, have entirely dissappeared, but those forms which seem to be of the better class and of more recent design have been more fully described.

In the preparation of the following, free use has been made of numerous publications relating to the subject, and references for further information are given in foot-notes throughout the thesis.

THE POWER REQUIRED TO DRIVE MACHINE TOOLS.

The problem, "to weigh a moving force", has probably been studied and experimented on to a greater or less degree since the time of Archimedes. However, various definite forms of machines to measure power have made their appearance during the last century and a half. Perhaps the most decided advance was made by James Watt in applying the indicator to the steam engine. The steam engine indicator is now the most accurate instrument we have for determining the power used by a steam engine, still sometimes it is difficult, in the case of a high speed engine, to work up, accurately, the cards obtained when running without a load, and in many cases as of water power, or in obtaining the power delivered from a belt, or gearing, an indicator card is impossible. To overcome this difficulty we turn to dynamometers, which have been defined as instruments for measuring power. They are of two general classes, although a third may be added. The two general classes are: (1) Absorption; (2) Transmission; and the third, Traction. In the first class the work received is transformed by friction into heat and dissipated; in the second class the dynamometer absorbs only so much force as is necessary to overcome its own friction, the remainder being transmitted, while in the third class the dynamometer simply registers the pull.

Of the first class, Absorption dynamometers,[1] the prony brake,[2] is the most common form.

There have been many attempts to produce an instrument which would measure the actual power consumed by any machine, while the power is being delivered from the prime mover whether engine, turbine, or dynamo, and such instruments are therefore of the second class viz: transmission dynamometers. Many of the earliest ones of this class, like the indicator, depended upon the compression or tension of springs. The amount of deflection of the spring was read in various ways, some by means of a graduated scale, others by means of weights which acted at a definite known distance from the center of the mechanism. The steam engine indicator, is an instrument which has come to have many and varied uses, and we find it in use on several types of transmission hydraulic dynamometers. It is found that the types using the steam engine indicator have, by far, given the most accurate and reliable results.

Other inventors, however, sought long ago to obtain a regular weighing machine, on the principle of the old Roman steelyards, and

1. For description of various forms of absorption dynamometers see the following:
   (a) Scientific Amer. Supplement Vol. 39 page 15851.
   (b) John J. Flather's treatise on Dynamometers and the measurement of power first,72 pages. Published by John Wiley and Sons New York.
   (c) Carpenters Experimental Engeering, page 207.
   (d) Prof. Jamieson's Text book on Applied Mechanics,Vol.I,page 144.
2. For description of various forms of prony brakes see the following:
   (a) Engine and Boiler Trials by R.H. Thurston page 157.
   (b) Machanics of Materials by I.P. Church page 269.
   (c) Du Bois Weisbach's Mechanics of Engeering, page 13.

the one which marks the advent of the transmission dynamometer into this country was the so called "balance dynamometer" introduced by Samuel Batchelder, then of Saco, Maine, in the year 1836, and at that time supposed to have been of his own invention. It has been found in the later researches that this machine was originally invented by Samuel White, of England, in the year 1780. As previously mentioned this dynamometer was called the "balance dyanmometer" or "differential dynamometer" it also bears the name of White, Batchelder, Trancis, Webber, and King, all of whom, with the exception of the first, modified the original design into a machine of their own design. It sometimes bears the name of Epicyclic Train.

Transmission dynamometers, according to Proffessor Jamieson, may be divided into two classes;- 1. those which help to measure the work transmitted by a belt or set of ropes; - 2. those which help to measure the work transmitted by a shaft. The term epicyclic train dynamometer, is applied to those of the second class of transmission dynamometers which help to measure the work of a shaft by transmitting the same through an epicyclic train.

Since this balance dynamometer marked the beginning of transmission dynamometers in this country a brief description of the machine will be given, taken from Flather.[4]

However before this is given let us look at the requirements of a dynamometer as set forth by Morin, something over a half century

4. John J. Flather's treatise on Dynamometers and the Measurement of Power, page 76.

ago. Viz,

FIRST. - The sensibility of the instrument should be proportioned to the intensity of effort to be measured, and should not be liable to alterations by use.

SECOND. - The indications of flexures should be obtained by methods independent of the attendance, fancies, or prepossessions of the observer, and should consquently be furnished by the instrument itself, by means of tracings, or material results, remaining after the experiments.

THIRD. - We should be able to ascertain the effort exerted at each point of the path described by the point of application of the effort, or, in certain cases, at each instant in the period of observations.

FOURTH. - If the experiment from its nature must be continued a long time, the apparatus should be such as can easily determine the total quantity of work expended by the motor.

The principle of the "balance dynamometer" is, that to hold a weight by the radius of a circle in a horizontal position takes as much power as to lift the same weight through the distance which would be traversed by it in any given number of revolutions, if rotated in the circle, and in the time required for such number of revolutions. We already see that this is the governing principle of the prony brake where the lever is maintained in a horizontal position, the work being estimated as though the weight suspended at the end of the lever rotated in a circle whose radius was equal to the

length of arm L. Though alike in principle, the methods by which this and the Morin dynamometer operate are radically different. The Batchelder, instrument, improved and modified, has been made by the Lawrence Machine Company, and known as the Webber balance dynamometer.

"On the receiving-shaft are fixed a pair of fast and loose pulleys at one end, and a spur-gear at the other. This spur-gear drives a corresponding gear of the same size and number of teeth, which is fixed on the end of a sleeve or collar, having on its other end a bevel-gear which forms one side of what is known as a 'box' or 'compound' gear. A corresponding gear on the opposite side of the 'box' is fixed on the delivering-shaft which passes through the sleeve above metioned, and also through the fulcrum of the scale beam. The two remaining sidesof the 'box' are composed of a pair of equal and similar gears, which revolve freely around the scale-beam on either side of the fulcrum. One would really be sufficient for the purpose, but a pair is used in order to preserve a balance. When motion is given to the shafts by means of a belt to the receiving-pulley, the intermediate gears revolve about the scale beam without effect; but when a belt is carried from the delivering-pulley to the machine to be tested, the resistance causes the intermediates to act with the effect of levers on the scale-beam, and would put the latter in revolution about its axis or fulcrum if it were not restrained by the weights, which are to be added, and adjusted until a balance has been obtained. It will be readily seen that the real motion of the scale-beam, were it free to move, would only be one half that of the

shafts, and the weights in actual use are therefore double their apparent value or in other words, the weight marked one thousand pounds is in reality two pounds instead of one."

The circumference of the circle through which the weight would travel, were it free to move, is ten feet, therefore we can readily calculate the horse-power from the following:

$$H.P. = \frac{P \cdot V}{33000} = \frac{P \times 2\pi R \cdot N}{33000};$$

since $2\pi R = 10$, we have,

$$H.P. = \frac{10 \cdot P \cdot N}{33000},$$

in which, P = pounds weight, N = revolutions per minute, and V = velocity in feet per minute.

The weights are marked for $N = 100$.

Another form is that known as the belt transmission dynamometer, used by Dr. Hopkinson in his tests with the Siemens dynamo- electric machines. The principle involved is the weighing of the resulting stresses from a deflected belt, and by this means ascertaining the direct stress upon the belt itself. To obtain a measure of the difference in belt-strain a dynamometer known as Brigg's Belt

Dynamometer was designed.[5]

This failed to meet the second, third, and fourth requirements as given above by Morin.

Another form which was designed by Morin to meet the requirements he set forth, was called the spring dynamometer. In this dynamometer a force was measured by flexure produced by it on two springs connected at their ends and loaded in the middle. In order to meet the second, third and fourth requirements which Morin set fourth, a self registering apparatus was used, by which the work performed was traced upon a continuous roll of paper, set in motion by suitable wheel work.[6]

Another form similar to Brigg's, was designed by W.P. Tatham,[7] of Philadelphia and constructed for the use of the Franklin Institute.[8]

The record is traced on a ribbon of proper size driven by a worm gear, and ordinates of the curve, traced by the pencil, plus the weights on the scale beam give the power which is being transmitted through the machine. This machine was capable of measuring power

5. John J. Flather's treatise on Dynamometers and the measurement of power, page 79.
6. See the following:
   (a) Carpenter's Experimental Engineering, page 219.
   (b) Tran. A. S. M. E. Vol 10, page 116.
   (c) John J. Flather's treatise on Dynamometers and the measurement of power, page 77.
7. For full description see:
   (a) Scientific Amer. Supplement Vol. 39, page 15852.
   (b) John F. Flather's treatise on Dynamometers and measurement of power. page 82.
8. See Journal of Franklin institute December 18, 1882.

from 0.23 H.P. to 70 H.P.

The Emerson power scale, is another form of instrument which is connected directly to the revolving shaft without the interposition of belts, except that used to drive the shaft itself. The machine in principle is a rotary scale, and its construction closely resembles the well known Fairbanks scales.[9]

Prof. J. Burkitt Webb of Stevens institute invented a dynamometer known as Webbs floating dynamometer.[10] This instrument gave a very great degree of accuracy as the friction of the fluid in which its body floated was reduced to a minimum.

Another form of Belt dynamometer[11] was designed by Messers Geo. Wales and F.M. Leavitt and built under the direction of Prof. Jas. E. Denton in 1883, for the use of the Chicago railroad Exhibit Committe, appointed to test dynamometers.

This apparatus was designed to make an autographic portable dynamometer on the belt angle principle, using the angle of the belt as the primary element of force measured.[12]

9. For more elaborate description see the following;
   (a) Machinery May 1898.
   (b) Carpenters Experimental Engineering, page 231.
10. See John J. Flathe's treatise on Dynanonetes and the measurement of Power, page 103.
11. Description of belt Dynamometer by S.P. Watt Trans. A.S. M.E. Vol. 1? page 6?4.
12. John F. Flather's treatise on Dynamometers and the measurement of Power, page 96.

The Van Winkle[13] dynamometer is a dynamometer similar to Emerson's power scale but so constructed that it may be used on a line shaft and the H.P. read directly from the pointer. Two of the Van Winkle dynamometers furnished to a firm in, Antofagasta, Chili, respectively of 450 and 600 horse-power capacity, at one hundred and twenty revolutions per minute transmit the power of two nine inch shafts. They are believed to be the most powerful rotary transmitting dynamometers, of any type, ever constructed.

Dr. Bedell designed a dynamometer[14] which was applicable to factories and power houses. It was so designed, that at a glance the engineer in charge could see the exact amount of power, which was being delivered and regulate his prime more to suit the demand.

Description of other forms of dynamometers, and information relating to the same will be found as follows:[15]

13. For description see:
    (a) Carpenter's Experimental Engineering, page 233.
    (b) Scientific Amer Sup. Vol.39 page 15853.
14. Trans. A. S. M. E. Vol. 18 page 669.
15. (a) Automatic Absorption Dynamometer by Geo.I. Alden. T.A.S.M.E. Vol.11 page 959.
    (b) The Measurement of power by Tjomas Gray T.A.S.M.E. Vol. 13, page 531.
    (c) Friction in transmission Dynamometers by S. Webber T.A.S.M.E. Vol. 10, page 514.
    (d) New Forms of Friction Brakes by W.F.M. Goss T.A.S.M.E. Vol.16 page 806.
    (e) The Lewis and Pillow block Dynamometer; Carpenter's Experimental Engineering, page 224 and 225.
    (f) A Simple Belt Dynamometer; Carpenter's Experimental Engineering, page 235 also Church's Mechanics of Materials.
    (g) Hachette's Steelyard-Dynamometers, Carpenter's experimental Engineering, page 222.
    (h) A Dynamometer patented by Horace C. Hovey, of Ayers Mass. American Machinist. Vol.9. Sept.11 - 1886 page 4.

The first dynamometer, which the writer found, using oil under pressure, to transmit the pressure to an indicator, was one designed and described by Prof. L.P. Breckenridge in the American Machinist Aug. 14 1890, from which the following is taken.

"Description of Aparatus. In Fig. 1 is shown a side view of the apparatus as it appears attached to the planer table A A by means of the usual angle plate. It consists of the cylinder C carefully bored to receive the plunger P, and tapped above for one-falf inch connections to the indicator as shown, also to a gauge not shown in Fig 1. The area of the cross-section of the plunger at right angles to its axis is exactly ten square inches, or about 3.57 inches in diameter. The plunger, which is solid cast iron, is 6 ins. long, and while in use extends out of the cylinder about one inch; the end of the plunger inside the cylinder has 3 grooves turned in it 3/32 inch wide and deep, and 1/2 inch apart.

Fastened to the head of the plunger is the cast iron angle piece B, which is 4 inches wide, and rests on two wrought-iron rolls R; the bearing of this piece B on the rolls is 1 inch at each edge, the middle of the under side being planed out so that the heads of the bolts

(i) For illustrations and descriptions of several dynamometers of minor importance see: S.A.S. Vol. 39, page [illegible] and [illegible]. Jan. 5 - 1895.

(j) A dynamometer used by Hartig: John J. Flathr's treatise on Dynamometers and the Measurement of Power, page 111; or Dubois' translation, Vol. II part I, of Weisbach's Machánics.

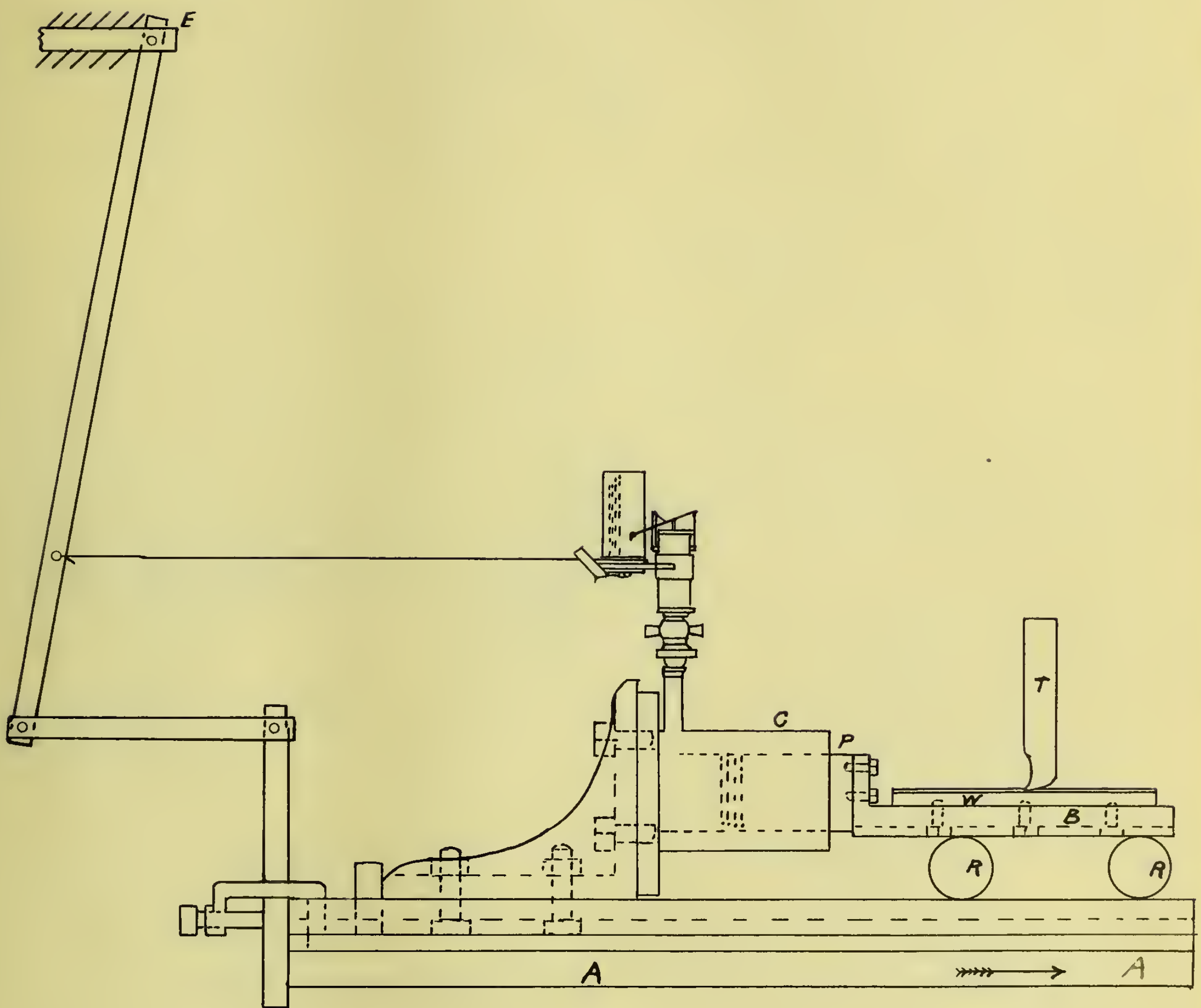


Fig. 1.

which fasten the piece W, which is to be planed, to the piece B, will not strike the rolls. The piece W is tapped to receive the cap screws used in fastening it to B.

The pieces planed were cast 3 inches wide, 12 inches long and 1 inch thick, the thickness being chosen so that the top surface came 3/32 inch above the axis of the plunger. It was thought that the most accurate results would be obtained when the tool was cutting along a line coincident with the axis of the plunger, but there was no noticeable difference in the pressures recorded for a space of 1 1/2 inch along the middle of the piece experimented upon.

The tool is shown in about the middle of a cut, and it must be regarded as stationary; the tool-box and its connections, as well as the bed of the planer, not being shown.

The reducing motion for the indicator is shown at the left. H, is a fixed point, the swinging lever and connecting link being moved back and forward by the piece clamped to the end of the planer.

A space of about 2 1/2 inches exists between the end of the plunger and the bottom of the cylinder. Into this space cylinder oil was turned, the plunger being pulled out about 2 inches during this time. When sufficient oil has been turned in, the plunger is slowly pushed into the cylinder, the indicator being open in order that all the air may be driven out, and when oil appears at the loose places, the indicator is screwed on and the apparatus is ready for use. The cutting speed of the planer was not as fast as many planers run. The cuts

taken were measured by calculations from the number of threads per inch on the cross and vertical feed rods. They varied all the way from light, to cuts heavy enough to stop the planer by running off the 2 1/2 inch belt, which was reasonably tight."

The following table contains a part of the seventy four experiments made, at the works of Bethlehem Foundry and Machine Company, South Bethlehem, Pa. by Prof. L.P. Breckenridge, on May 8, 1889, with the above described apparatus. Several of the indicator cards are shown on the following page, the number of the card corresponds to the number of the experiment.

Material planed, cast iron.

Width of cut = rate of feed (see colium i).

Paragraph (a) Velocity of tool while cutting = 10.6 feet per min.

Springs used in indicator (44-49) 40# (50-74) 80#

Length of diagram 3.18"

No. of Exp.	Depth of cut in inches	Aver. pres. by guage #	Area of Diagram sq in.	M.E.P. by Diagram pounds	Total pres. against tool #	Ft-pounds of wk. per min. to plane iron.	H. P. required to plane iron.	i.
44	0.017	52	3.86	48.6	486	5152	0.156	.083
45	0.017	55	4.30	54.2	542	5745	0.174	.083
50	0.017	65	2.55	64.3	643	6816	0.206	0.126
54	0.050	120	4.58	115.4	1154	12190	0.370	0.117
56*	0.050	125	4.78	120.4	1204	12720	0.385	0.117
59#	0.017	40	1.36	34.2	342	3625	0.109	0.055
62	0.017	40	1.34	33.7	337	3572	0.100	0.055
65	0.033	57	2.02	50.9	509	5395	0.163	0.055
68	0.050	70	2.61	65.7	657	6964	0.211	0.055
73	0.083	105	3.79	95.5	955	10123	0.306	0.055

*Spring of work or tool, see card.

#Blow holes, see card.

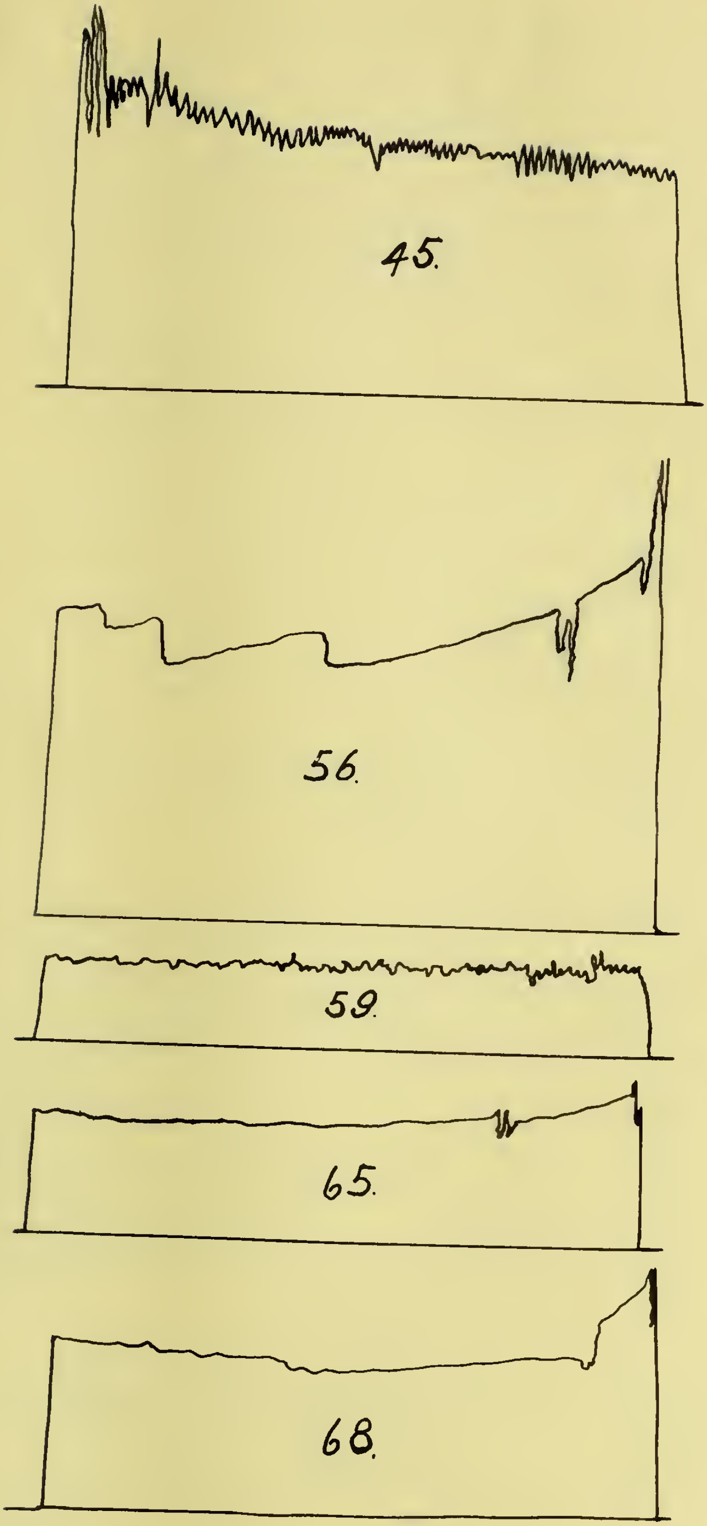


Fig. 2

A few years after Prof. L.P. Breckenridge had made his experiments John J. Flather constructed an apparatus very similar to the one just described and shown in Figs 7 & 4. In both these dynamometers oil under pressure was used, and the work performed was obtained from the card. It is evident that the total work performed cannot be obtained by this means, as the force required to drive the machine itself is disregarded.

To obtain the total work, and at the same time the useful effect, Prof. J.J. Flather next designed a hydraulic dynamometer. The principle of this machine will be seen ny examining Fig 3. The plan of mounting the cylinder upon a rotary pulley was obtained, by Prof J.J. Flather, from an article which appeared in Industries,[16] but the details and arrangement of the dynamometer designed by Prof. Flather, are in many respects very different from the one there illustrated.

The design, of Prof. J.J. Flather, was modified by James D. Hoffman, of Lafayette Indiana, and a hydraulic dyamometer designed and constructed, which seemed to give very satisfactory results. This machine was constructed at Purdue University in the winter of 1894-95 to make series of tests on the application of cutting edges to iron.

The[17] main features of the machine are as follows: Two cylinders, E E; (Fig 3), are fastened diametrically opposite each other to a

16. See also Sc. American Sup., Feb. 9, 1889.
17. Taken from Transactions A.S.M.E. Vol. 17, page 471.

double yoke, which in turn is fastened to a hollow shaft. Each cylinder is connected to the centre of the shaft by the hollow tubing and ground joint shown at a'; The cylinders are rotated; that is, the shaft is rotated by the pull of the driving belt on the loose pulley A, tending to force the brass pistons to the bottom of the cylinders. The shaft and cylinders are full of oil, and any fluctations of power between A, the receiving, and C, the delivering, pulleys, are shown in pounds on the gauge to the right, and an indicator card on the left hand. The oil flows around the bearing G, giving good lubrication, and is kept from leakage by means of the stuffing-box shown in the section (Fig. 4). By a number of interchangeable gears, the paper has different speeds, which is of much importance in taking cards where sudden changes of resistance appear, such as turning iron of an uneven texture, or the short, quick stroke of the shaper.

In working up the cards, the area and length are measured accurately, and the mean height (M.H.) obtained. This M.H. is converted into M.P. by calibrating the machine and finding the value of the resisting spring under the casting, b' (Fig. 3).

The recording device is designed to give a straight line motion, at the end of the pencil arm. A bronze point and metallic-surfaced paper are used. No flexible material, such as cup leather, is used in the cylinders, and the pistons fit loosely enough to reduce the friction to a minimum. When the oil runs low by leakage, it is the work of but a few minutes to replenish, by means of the pump at the rear. The leakage does not exceed a half pint daily when doing ordinary duty.

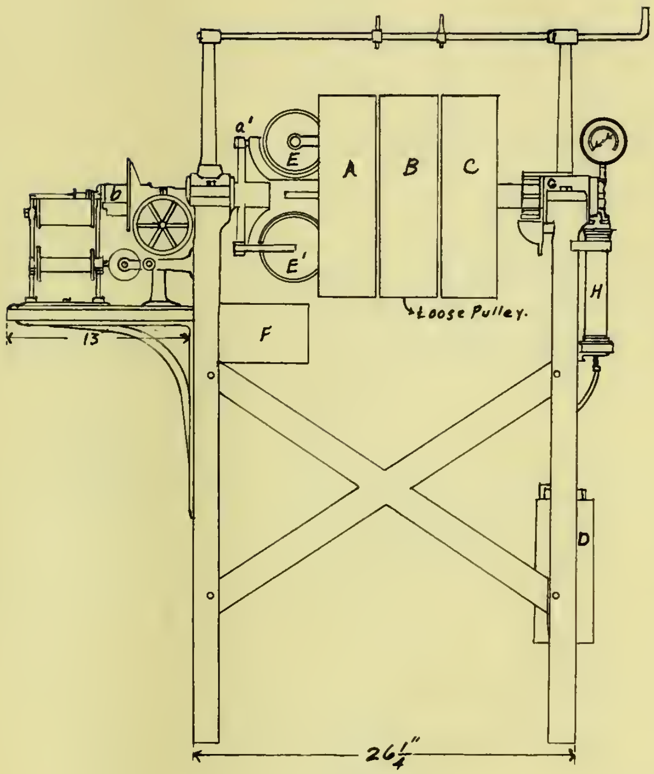


Fig. 3

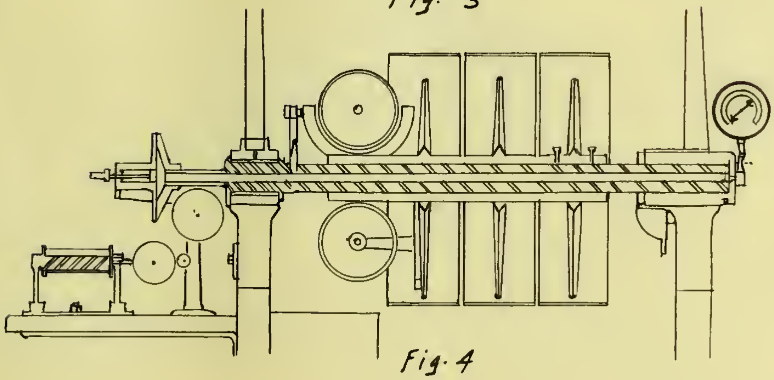


Fig. 4

When in use the cylinders are surrounded by a sheet-iron case to catch the oil.

CALIBRATING THE HOFFMAN MACHINE.- To do this, pulley C (Fig. 3). was held stationary by means of a lever wired to the floor. Two thirty pound gauges were selected and tested in the laboratory for this purpose. Readings were taken from each gauge and averaged for results. By a downward pressure on the lever, (the pulley A, held stationary by wire to the floor), the gauge was brought to read exact pounds, and at these readings the paper was moved, giving lines parallel to the base line.

To insure the pencil returning each time to the same line when the load is removed, a constant pressure is put on the spring when the piston in Fig. 3 is against the stop. A stationary bronze point is set to record this line, and all measurements are taken from it. The zero line is below the base line, a distance readily determined when the scale of the spring is known. As an additional check to any error which might occur in the above calibration, the spring is tested by means of a differential arm.

In its use the dynamometer has possibly been more accurate when opperated by differences; that is, take a card of the machine (lathe or planer) in motion without cutting; then a card following, with the tool in operation. The differences in the heights of the cards are evidently due to the action of the tool.

A few of the cards have been added to show how readily the recording device responds to any slight change in the power transmitted.

FIG. 5 is taken from a 12 X 18 tracing, and serves to show the gradual reduction in height of the card as the diameter of the stock decreases; also, to compare the relative heights of cards for different metals.

The card as it comes from the dynamometer is four inches wide, shown at A, B, C, D.

The friction of the machine and work was such a variable quantity, especially so considering the pressure, on the tail centre, that it was found necessary to take friction cards at intervals during the series, as E, F, G, H.

The following tables give the data for one test taken in an 18-inch Reed lathe. The tool was sharpened before each cut, and the conditions surrounding the cutting edge of the tool were kept constant throughout the series. The cutting action only is recorded.

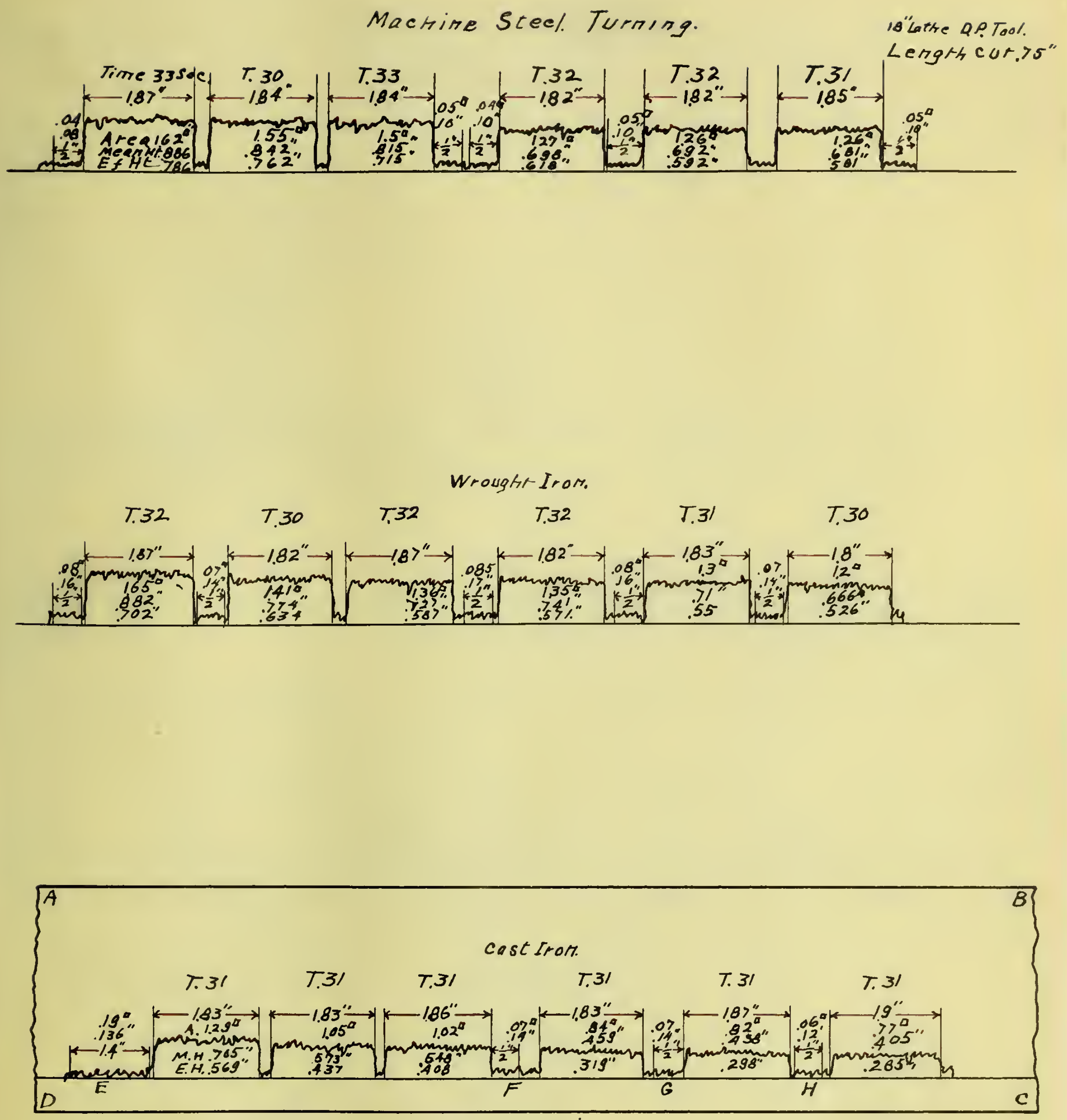

Machine Steel Turning.
18" Lathe Q.P. Tool.
Length cut .75"
Time 33 Sec.
T. 30
T. 33
T. 32
T. 32
T. 31
1.87"
1.84"
1.84"
1.82"
1.82"
1.85"
Area 1.62"
Mean Ht. .886
Ef. Ht. .786
Wrought Iron.
T. 32
T. 30
T. 32
T. 32
T. 31
T. 30
1.87"
1.82"
1.87"
1.82"
1.83"
1.8"
A
B
Cast Iron.
T. 31
T. 31
T. 31
T. 31
T. 31
T. 31
1.83"
1.83"
1.86"
1.83"
1.87"
1.9"
1.4"
A. 1.29"
M.H. .765"
E.H. .569"
D
E
F
G
H
C

Fig. 5.

18 inch lathe. Back Gear Out. Slowest Speed, R.P.M. of dynamometer, 112. R.P.M. of lathe, 62. Diamond point tool. Constant .324.

TURNING	CAST IRON			WROUGHT IRON		
	M.E.H.	AV. M.E.H.	M.E.P.	M.E.H.	AV. M.E.H.	M.E.P.
	.317			.710		
1 7/8" - 1 3/4"	.569	.447	1.379	.702	.705	2.175
	.455			.702		
	.324			.633		
1 3/4" - 1 5/8"	.437	.407	1.256	.680	.649	2.003
	.460			.634		
	.283			.536		
1 5/8" - 1 1/2"	.408	.359	1.108	.570	.564	1.740
	.387			.587		
	.282			.643		
1 1/2" - 1 3/8"	.319	.297	.916	.561	.592	1.826
	.291			.571		
	.237			.556		
1 3/8" - 1 1/4"	.298	.275	.848	.528	.545	1.682
	.291			.550		
	.208			.535		
1 1/4" - 1 1/8"	.285	.245	.756	.503	.521	1.609
	.241			.526		

TURNING	Machine Steel.		
	M.E.H.	AV. M.E.H.	M.E.P.
	.786		
1 7/8" - 1 3/4"	.782	.793	2.447
	.812		
	.762		
1 3/4" - 1 5/8"	.732	.747	2.305
	.748		
	.715		
1 5/8" - 1 1/2"	.650	.657	2.027
	.605		
	.618		
1 1/2" - 1 3/8"	.672	.640	1.975
	.631		
	.592		
1 3/8" - 1 1/4"	.540	.550	1.697
	.519		
	.581		
1 1/4" - 1 1/8"	.565	.534	1.648
	.456		

WEIGHT PER. CU. INCH.			CAST IRON .26		
Feed: C.I. - 1.48" W.I. - 1.45" Steel- 1.4"	Cutting Speed.	Reduction in area.	Volume per Minute.	Weight per hour.	H.P.
1 7/8" - 1 3/4"	24.4	.356	.527	8.22	.187
1 3/4" - 1 5/8"	27.4	.331	.490	7.64	.171
1 5/8" - 1 1/2"	25.4	.307	.454	7.10	.150
1 1/2" - 1 3/8"	23.4	.282	.417	7.51	.134
1 3/8" - 1 1/4"	21.3	.258	.382	5.96	.115
1 1/4" - 1 1/8"	19.3	.233	.345	5.38	.103
Aver.				6.80	.142

WEIGHT PER. CU. INCH.			WROUGHT IRON. .28		
Feed: C.I. - 1.48" W.I. - 1.45" Steel- 1.4"	Cutting Speed.	Reduction in area.	Volume per Minute.	Weight per hour.	H.P.
1 7/8" - 1 3/4"	24.4	.356	.516	8.67	.295
1 3/4" - 1 5/8"	27.4	.331	.480	8.07	.272
1 5/8" - 1 1/2"	25.4	.307	.445	7.48	.236
1 1/2" - 1 3/8"	23.4	.282	.409	6.87	.248
1 3/8" - 1 1/4"	21.3	.258	.374	6.28	.228
1 1/4" - 1 1/8"	19.3	.233	.338	5.68	.218
Aver.				7.17	.249

WEIGHT PER. CU. INCH.				STEEL. .284	
Feed: C.I. - 1.48" W.I. - 1.45" Steel- 1.4"	Cutting Speed.	Reduction in area.	Volume per Minute.	Weight per hour.	H.P.
1 7/8" - 1 3/4"	24.4	.356	.498	8.49	.332
1 3/4" - 1 5/8"	27.4	.331	.463	7.89	.313
1 5/8" - 1 1/2"	25.4	.307	.429	7.31	.275
1 1/2" - 1 3/8"	23.4	.282	.395	6.73	.268
1 3/8" - 1 1/4"	21.3	.258	.361	6.15	.230
1 1/4" - 1 1/8"	19.3	.233	.326	5.56	.224
Aver.				7.02	.274

In finding the weight of metal removed per hour, the constants .26, .28, and .284 were used for the weight of one cubic inch of cast iron, wrought iron, and steel respectively. The cutting speeds were taken from the mean diameters (1 13/16, 1 11/16, and 1 9/16).

From the foregoing a relation can be established between the weights of chips removed per hour and the horse-power used, such that H.P. equals C W.

Where C = a constant and, W = wt. of metal removed, per hour.

For steel, H P equals .039 W.

Wrought iron H P equals .0347 W.

Cast iron H P equals .021 W.

Comparing[18] these results with those of Hartig and Smith we have for "Constant C":

	Cast-iron	Wrought-iron	Steel
From above table ----------	.021	.0347	.039
Hartig.[19] ----------------	.030	.032	.047
Smith.[19] -----------------	.027	.028	.042

The average pressure exerted at the point of the tool was found to be: cast iron, 192 pounds; wrought iron, 337 pounds; and steel 371 pounds.

The foregoing review, and descriptions, so far as the writer was able to find, covers rather fully the entire subject of dynamometers and brings it, particularily transmission dynamometers, down to the present time. The development of the various methods and instruments, "to weigh a moving force" may be readily traced from the first crude forms down to the present time. At present the better forms of

18. The steel and cast iron test pieces were of the best quality. but the wrought iron was below the average.
19. Taken from "Flather's Measurement of Power."

transmission dynamometers use oil under pressure, which in turn transmits the pressure to an indicator, which has been designed and attached in such a manner as to give a continuous record of the power being transmitted. We also see that the dynamometer designed by Prof. J.J. Flather and James P. Hoffman fulfilled the four requirements set forth by Morin; given on page six.

A HYDRAULIC BELT DYNAMOMETER.

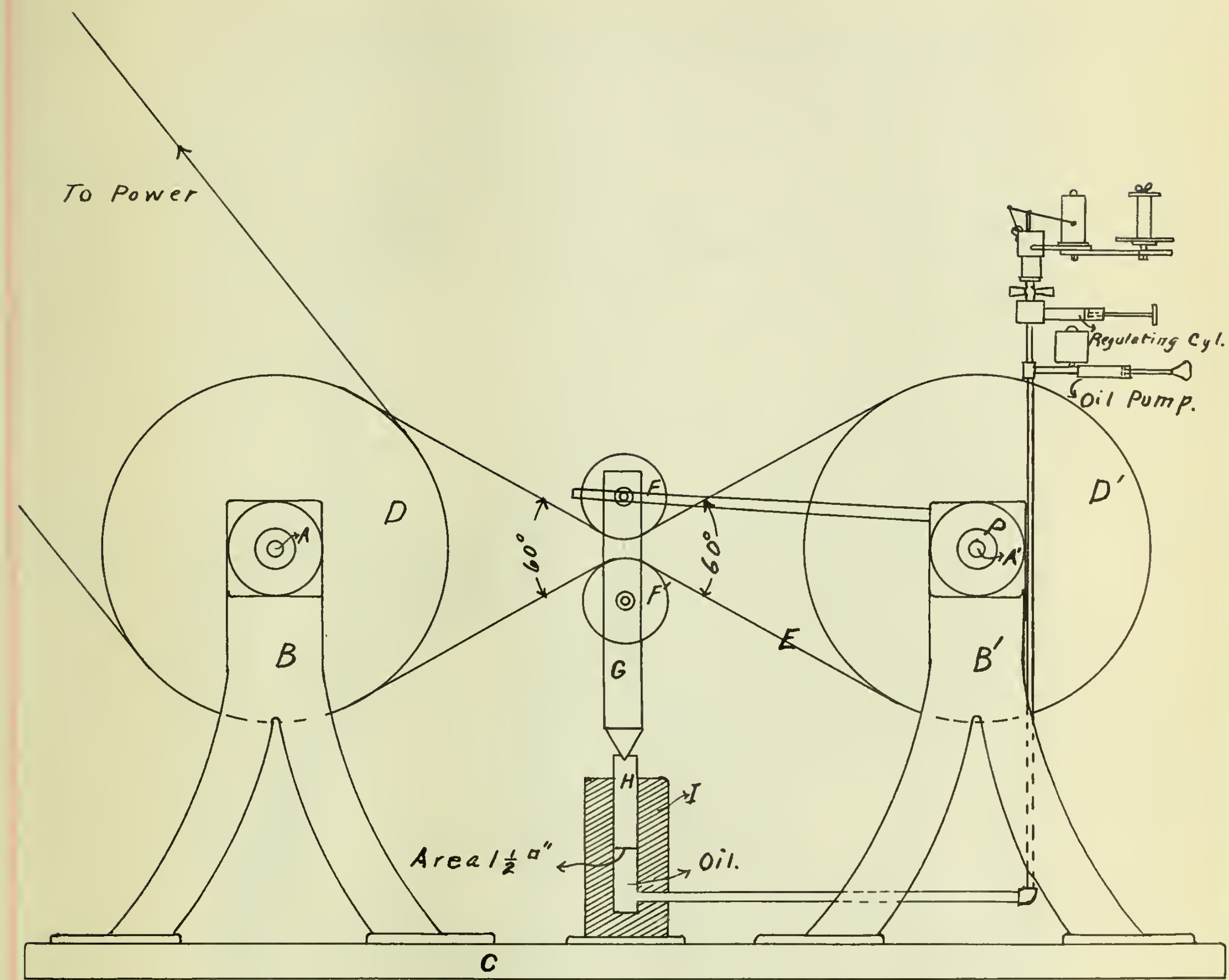
The original design and drawings of the above machine were made, several years ago at the University of Illinois, by a member of the class in advanced machine design. During the year 1901-1902, for thesis work F.L. Drew revised and completed these drawings. The machine was constructed in the shops of the University of Illinois, where he made a number of experiments on various machine tools.

The writer obtained the above machine from F.L. Drew and made such changes in design and construction as seemed best to accomplish the desired work. The main features of the machine are as follows: Two shafts A A' Fig 6 are supported in ball bearings, these being supported by stands B B' from the base C. Upon shafts C C' and between the stands are two 14" pulleys D D' these pulleys carry a belt E, which is caused to make an angle of 60° with itself by means of the guide pulleys F F'. The guide pulleys are mounted on ball bearings which are supported by frame G. This frame G, see Fig. 6 , is held in place by means of braces from stand B' and the lower end of G resting on the plunger H. The plunger H is free to act in cylinder

I, against the oil in cylinder, and hence through 1/2" pipe causes pressure against the indicator piston which actuates the pencil in the usual manner.

The recording device (see Fig 7) is designed to give a straight line motion, at the end of the pencil arm. A roll of paper being placed on the feeding spool A, the paper is threaded around the indicator drum B (which is covered with rubber, a piece of an inner tube of a bicycle tire) having an arc of contact of something over 210°, depending on the relative sizes of the rolls on spools A and D, and then passing to the receiving spool D. The indicator drum B is driven from a counter shaft, which in turn is driven from main shaft A''see Fig. 6) of dynamometer. The receiving spool is revolved by means of a friction drive (see Fig. 7) which in turn is driven from the small shaft of the indicator by means of a pair of gears. The tension in the paper is regulated by tightening a thumb screw on the feeding spool A, and by tightening the thumb screw on spool D, the latter increasing the friction between spool D and its driver. The paper is driven from the indicator drum B, and the receiving spool D keeps the paper taut. It will be seen that as the roll on the receiving spool increases in size, the friction drive easily slips and does not tear the paper.

No flexible material, such as cup leather is used in the cylinders and the pistons fit loosely enough to reduce the friction to a minimum. When the oil runs low by leakage, it causes the angle between the belts to vary slightly, to overcome this the regulating



Diagramatic Sketch

of

Transmission Dynamometer.

Fig. 6.

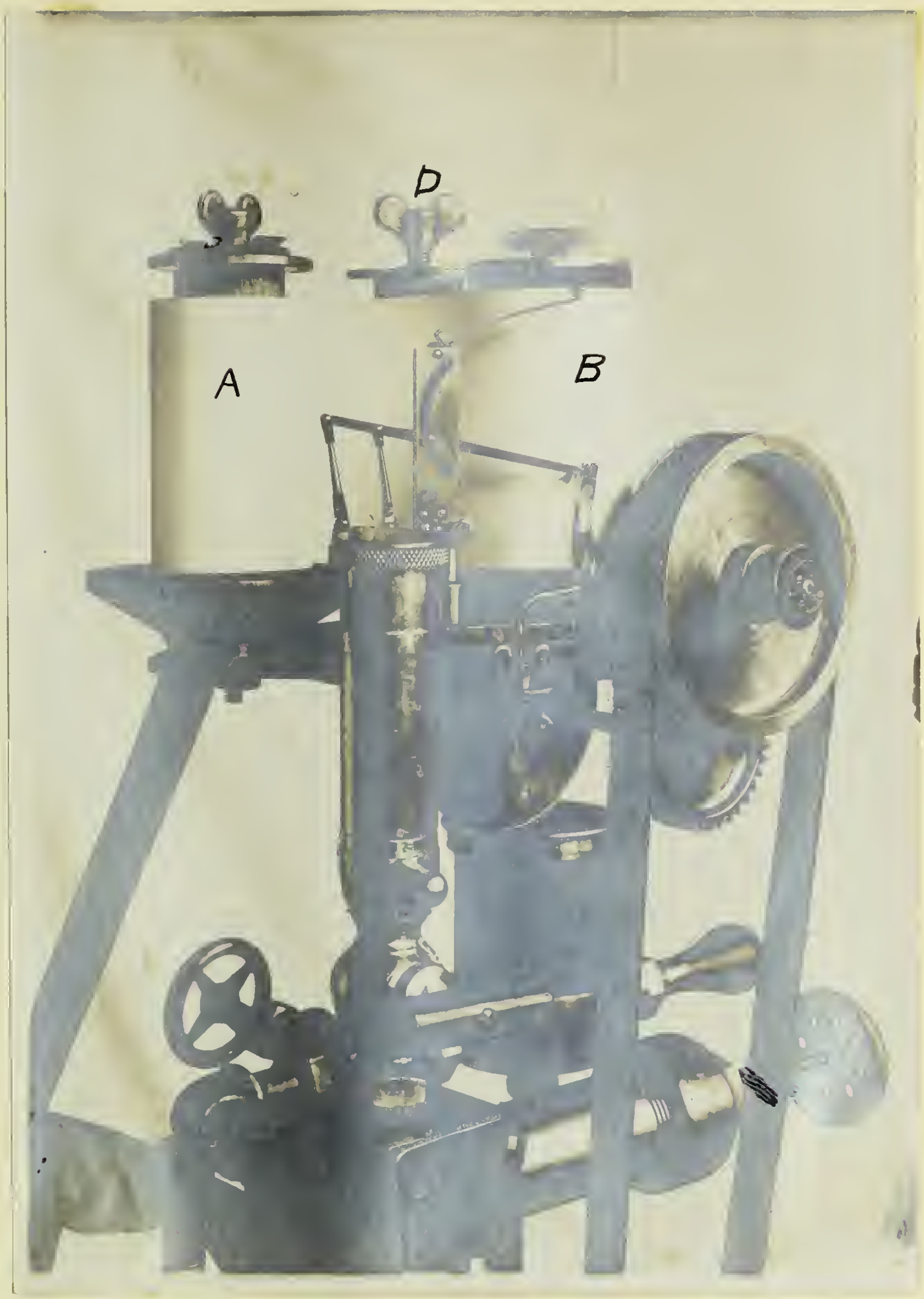


Fig. 7.

Recording device.

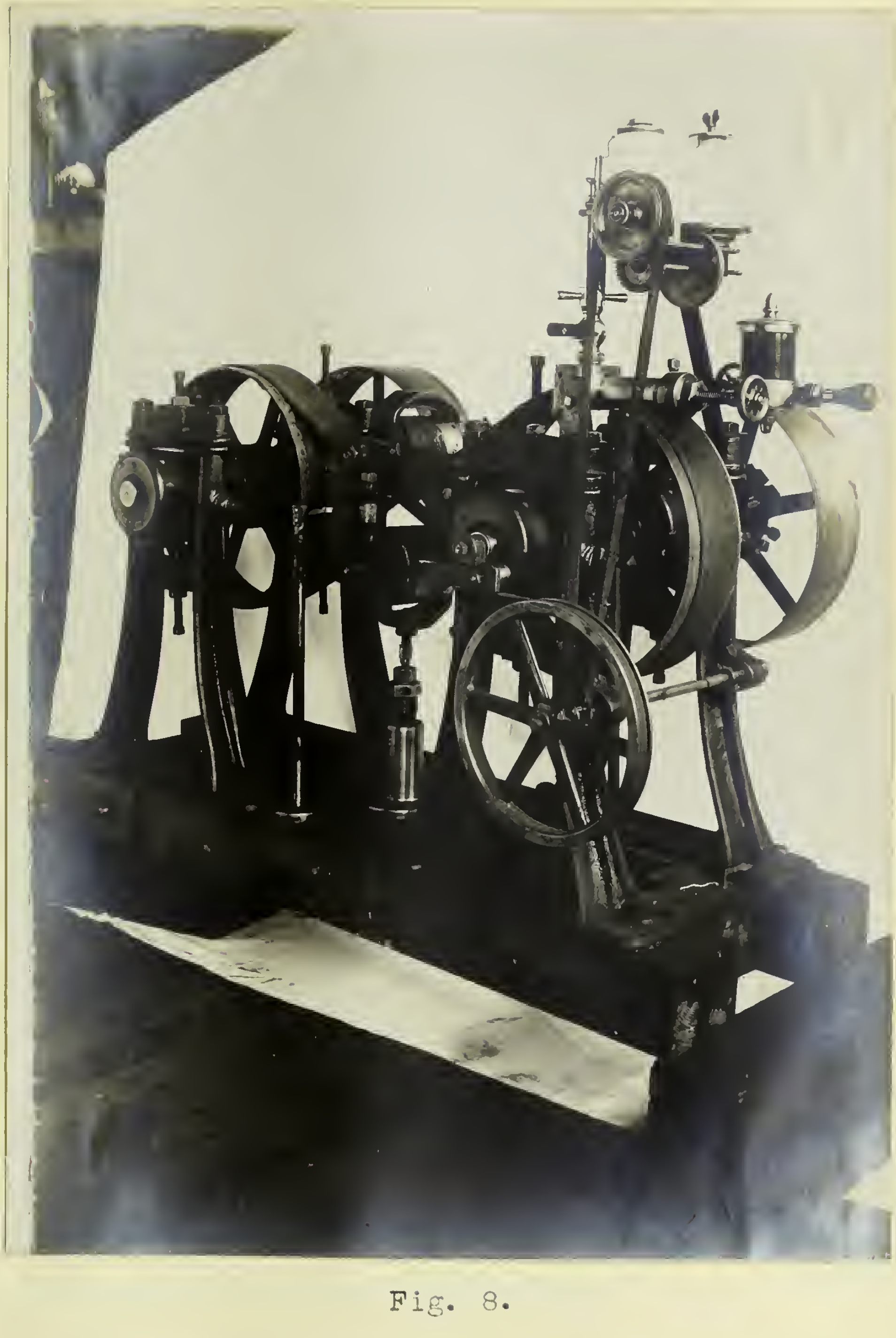


Fig. 8.

Belted Dynamometer.

cylinder (Fig. 7) is used. This leakage is very small in fact it is not noticeable in a test of two hours. A pointer E (see Fig. 8) is arranged so that the angle between the belts may be kept 60°. The position of this pointer is fixed before the machine is started, having first set the angle of the belts 60° by means of a protractor. The piping also contains connections to a small pump which supplies the oil in case of leakage.

The principle upon which this Hydraulic Belt Dynamometer depends is given in the following:

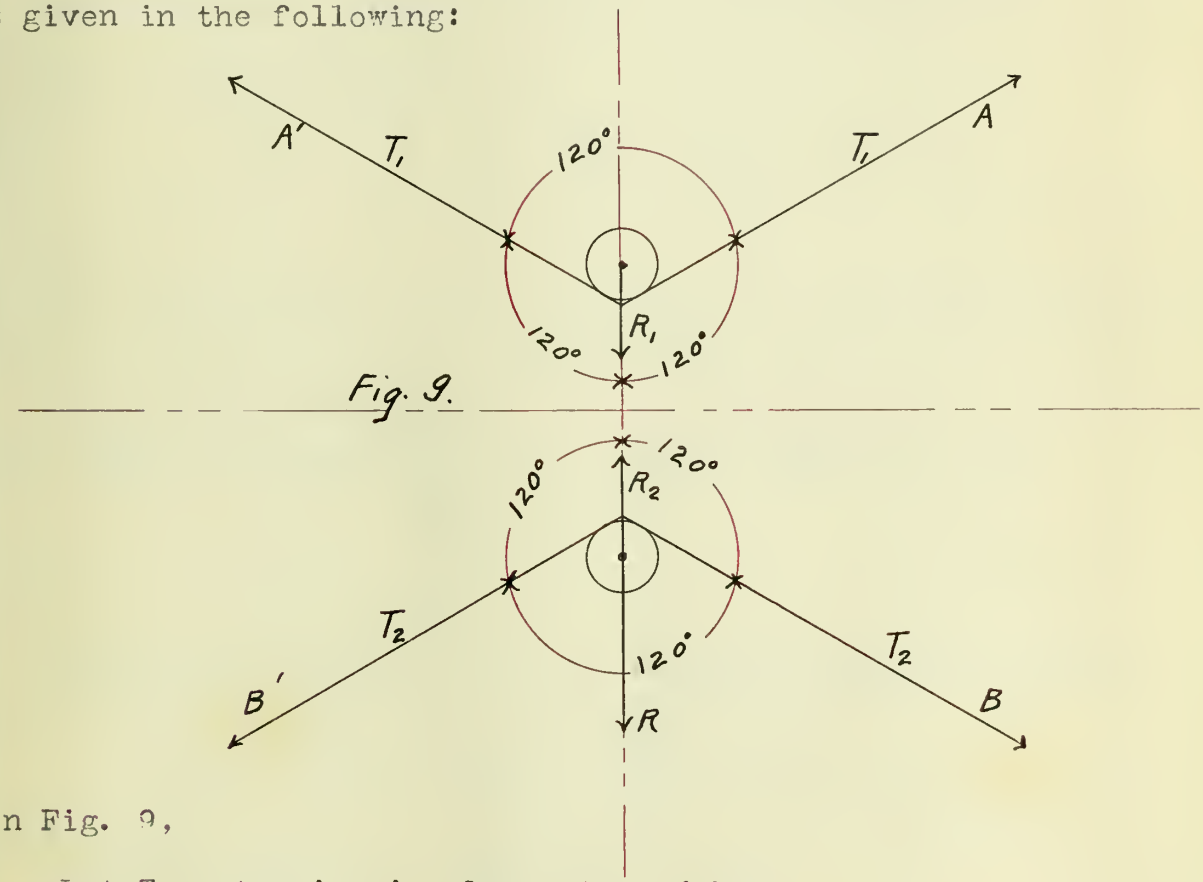


Fig. 9.

In Fig. 9,

Let T_1 = tension in slack side of belt.

and T_2 = tension in tight side of belt.

also belt A makes an angle of 60° with belt B.

Now since the power transmitted by a belt depends upon the difference

in tension of the two side of the belt, the problem becomes, to determine this difference, or to prove $T = T_2 - T_1$.

Neglecting friction in ball bearings of guide pulleys,

$$T_1 = T_1$$

and

$$T_2 = T_2$$

Now since belt A makes an angle of 60° with belt B,

We have the angle between A and A' $= 120^\circ$

also " " A " R_1 $= 120^\circ$

and " " A' " R_1 $= 120^\circ$

In like manner B, B', and R_2 make angles of 120° with each other.

Now, if three concurring forces acting at angles of 120° with each other are in equilibrium the three forces are equal.

Then $T_1 = R_1$

and $-T_2 = R_2$

but R_1 and R_2 act in the same straight line, and $R_2 > R_1$

hence $R = R_2 - R_1$

$= T_2 - T_1$

$= T$

$\therefore$ The vertical downward force which acts against the oil plunger is equal to the difference in tension of the belts. Q.E.D.

Now since the force R gives the difference in tension of the belts,

and this is transmitted by oil to the indicator as shown in sketch, the pencil of the indicator properly registers the tension difference of the two belts. This difference in tension bears a direct relation to the horse power which is being transmitted through the belts.

The dynamometer was first calibrated, and a factor, or constant, determined such that if the area of the chart in square inches be multiplied by the scale of the indicator spring and the constant, the product would be the H.P. transmitted. Although this calibration is not used at present it will be given in the following.

MANNER OF CALIBRATING THE MACHINE.

For arrangement of machine during calibration (see Fig. 10). The power to drive the dynamometer was taken from a small vertical engine. The power transmitted through the dynamometer was measured by means of the prony brake and scales. A load of five pounds was carried on the scales, which were balanced by regulating the brake. A test at a speed of 175 R.P.M. was run for ten minutes, all observations being taken every minute, and recorded on the card from indicator. Observations taken were; R.P.M., time, load, and minute marks on the card. These gave areas on cards from which H.P. is calculated. Eight tests were taken with varying speed and varying load.

To prepare the dynamometer for use it is belted up as shown in (Fig. 8), the oil pipes, cylinders, and cavities are now pumped full of cylinder oil, the large plunger which is under the guide pulleys, and the indicator piston being first removed; Now when oil appears

Fig. 10.

Arrangement for calibration.

and overflows the large cylinder, the plunger is inserted, and forces the oil out through the indicator, then we know that all the air has been driven out of the oil space, and the indicator piston is now inserted. The leads in the pencil holders are sharpened, the datum pencil is adjusted and the machine is ready for use.

Care must be taken to keep the pointer at its proper position, by means of the regulating cylinder.

CALIBRATION OF HYDRAULIC BELT DYNAMOMETER.

Test No.	Time	Wt. on Scales.	R.P.M.	Test No.	Time.	R.P.M.	Weight on Scales.
	3:18	5#	196		9:33	418	5#
	3:19	"	186		9:34	415	"
	3:20	"	195		9:35	414	"
	3:21	"	186		9:36	416	"
1.	3:22	"	180	3.	9:37	420	"
	3:23	"	167		9:38	419	"
	3:24	"	163		9:39	419	"
	3:25	"	163		9:40	420	"
	3:26	"	161		9:41	418	"
	3:27	"	155		9:42	422	"
		Average	175.1		Average	-419.1	
	3:30	"	314		9:49	408	"
	3:31	"	312		9:50	413	"
	3:32	"	312		9:51	411	"
	3:33	"	312		9:52	414	"
	3:34	"	312		9:53	404	"
					Lost 2min.		
2.	3:35	"	312	5.	9:55	414	"
	3:38	"	308		9:56	412	"
	3:39	"	308		9:57	415	"
	3:40	"	313		9:58	412	"
	3:41	"	312		Average	411.2	
		Average	312				

CALIBRATION OF HYDRAULIC BELT-DYNAMOMERER.

Test No.	Time.	R.H.P.	Wt. on Scales.	Test No.	Time.	R.P.M.	Weight on Scales.
	10:04	332	10#		10:43	198	15#
	10:05	330	"		10:44	198	"
	10:06	328	"		10:45	208	"
	10:07	332	"		10:46	206	"
5.	10:08	332	"	7.	10:47	212	"
	10:09	332	"		10:48	210	"
	10:10	331	"		10:49	206	"
	10:11	332	"		10:50	206	"
	10:12	333	"		10:51	204	"
	10:13	334	"		10:52	206	"
	Av.	331.6				205.4	
	10:18	200	"		1:19	376	20#
	10:19	196	"		1:20	374	"
	10:20	190	"		1:21	377	"
	10:21	192	"		1:23	378	"
	10:22	194	"		1:24	376	"
6.	10:23	192	"	8.	1:25	378	"
	10:24	206	"		1:26	378	"
	10:25	216	"		1:27	378	"
	10:26	228	"		1:28	379	"
	10:27	236	"		1:29	378	"

Av. 205

Average 377.2

METHOD OF CALCULATIONS.

Formulae for calculating Brake horse power.

$$B.H.P. = \frac{2\,\pi\ 30.875\ R.P.M:\ Brake\ load}{12.33000}$$

Formulae for calculating dynamometer horse power.

$$D.H.P. = \frac{T.\ R.P.M:\ 7.40.15\ \pi}{12.33000}$$

Where T = Mean height of card minus height with no load.

Radius of pulley = 7"

Scale of spring = 40#

Area of plunger against oil = 1.5 sq in.

The R.P.M. was taken with a speed counter.

Brake arm length = 30.875 inches.

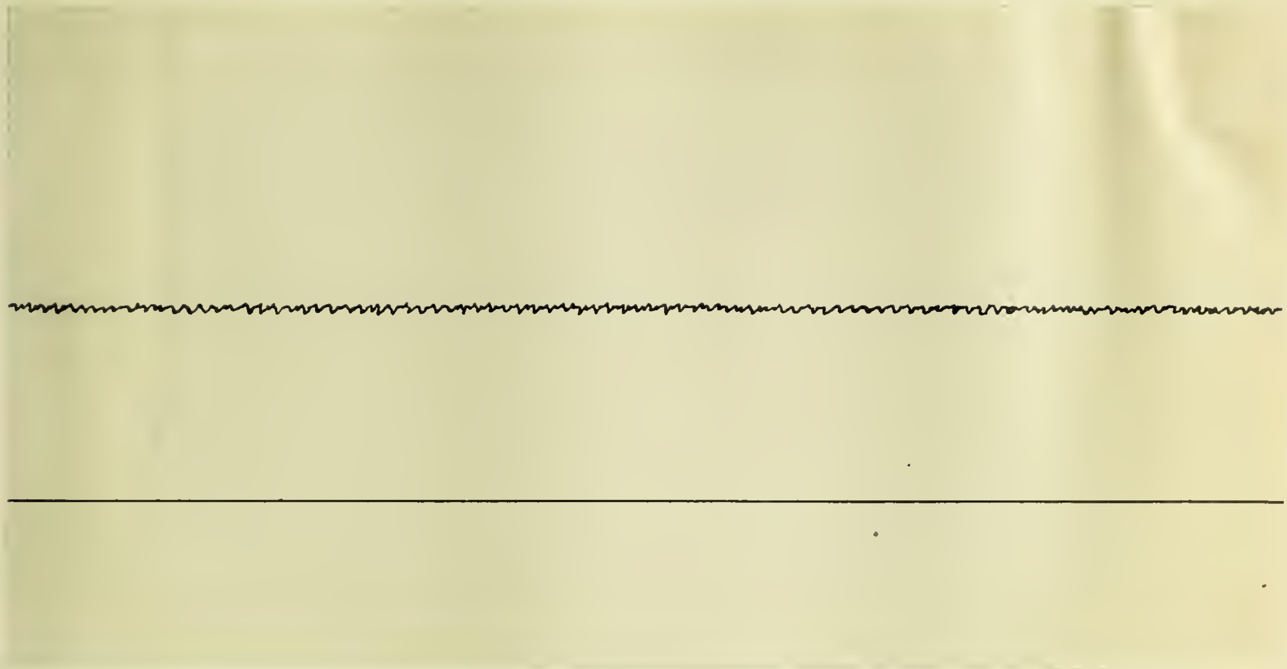
Scale of spring = 40#.

Summary of Data and Results of Calibration.

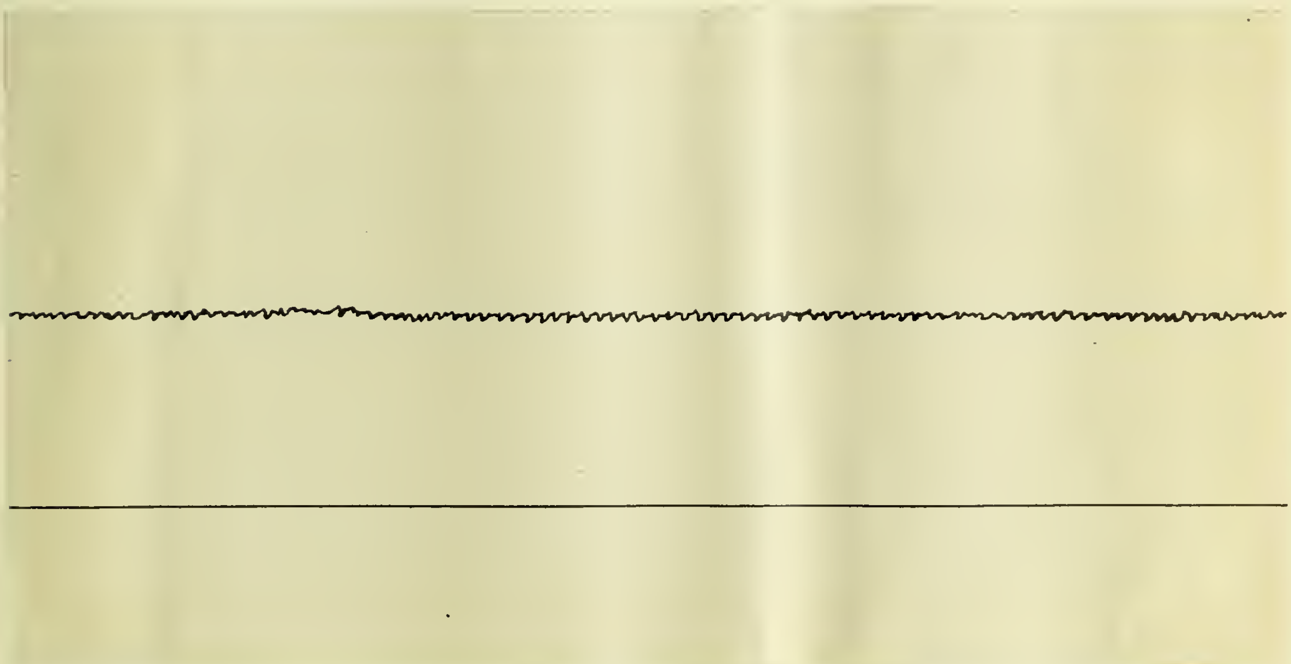
Test No.	B.H.P.	Area of Chart sq in.	R.P.M.	Time. min.	Factor by which to multiply.	Remarks.
1	.488	23.	175.2	10	.00477	A=actual area of chart.
2	.762	38.3	312	10	.00592	S = Scale of spring.
3	1.0225	64.5	419.1	10	.00405	
4	2.015	97.3	411.2	9	.0053	No 2 and 7 were rejected.
5	1.622	88.7	331.6	10	.0047	
6	1.0015	57.1	205.7	10	.00484	
7	1.55	70.8	205.4	10	.00563	
8	3.69	185.2	377.2	10	.0051	
				Ave.	.00496	
1	.858	46.95	175.2	10	.00517	
2	.733	36.13	299.4	10	.00468	
3	.99	20.65	405.2	5		
4	.963	53.41	197.4	10	.00461	No 3 and 6 were rejected.
5	1.523	86.71	311.5	5	.00451	
6	1.956	47.84	399.6	10		
7	1.512	80.97	205.8	10	.00479	
8	2.279	124.68	310.2	10	.0047	

Ave. .00474

Total Ave. .00485



1st Calibration, Wt. on Scales, 5#.



1st Calibration, Wt. on Scales, 5#.

Final Summary of Calibration.

In first series test No. 2 and 7 were rejected, since results did not compare closely with the other six, as was shown on a rough curve plotted with, Delivered horse power and Factor as ordinates and abscisna respectively. In second series tests No. 3 and 6 were rejected for other reasons than their close comparison.

$$\text{Factor} = \frac{\text{B.H.P.}}{\text{Area of chart} \times \text{scale of spring}}$$

The factors of both series were averaged by throwing out the enoneous results.

Average factor of both tests = 0.00485.

In the foregoing calibration it was also necessary to calibrate the indicator spring and correct the readings accordingly.

However a part of the paper roll machanism was changed and it was necessary to calibrate the machine again. Several changes and improvements were made from time to time.

The writer now conceived the idea of determining a factor or constant which if multiplied by the area of the chart would give the H.P That is, the indicator spring (now a 50# spring) was calibrated in with the dynamometer. This calibration also eliminates the greater part of the friction of the machine. Another improvement on the old form of calibration, was to run the test during ten, fifteen, twenty or twenty five minutes and take the revolutions of dynamometer for the total

time. Dividing this by the number of minutes will give the R.P.M. This method eliminates the error of starting and stopping the counter and the personal error in getting the axact minute.

In the following calibration the datum pencil was set to correspond with the indicator pencil, i. e. both lines coincide, when the machine is running light, hence no subtraction of height, for weight of angle pulleys, friction of machine etc. is necessary.

SECOND CALIBRATION.

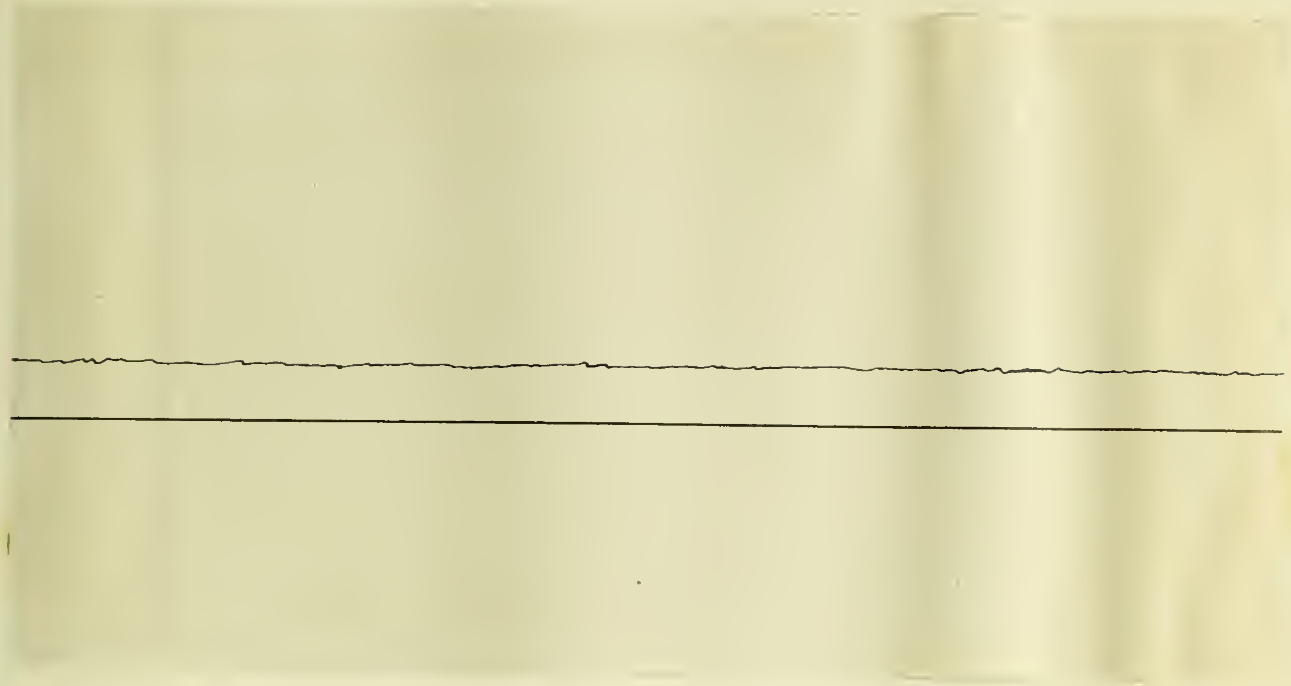
Length of Prony brake arm. 30.875"

Scale of indicator Spring = 50 #

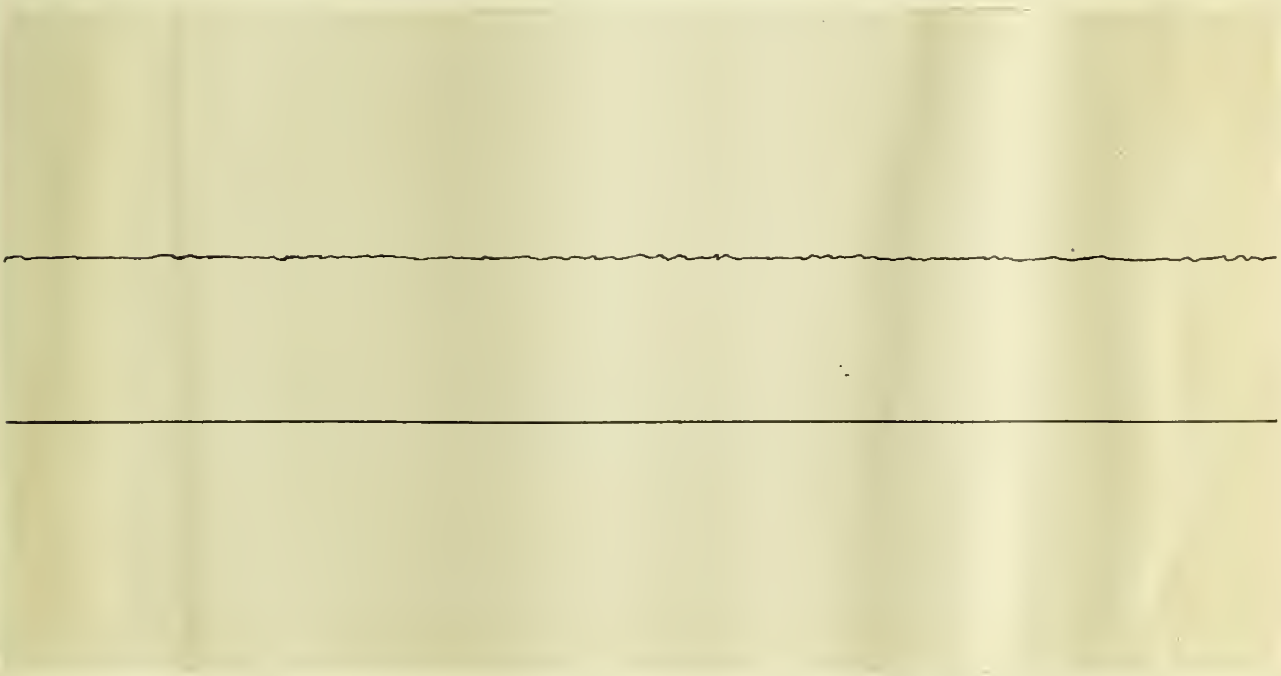
Test No.	Time min.	Total B.H.P.	Total area of chart sq. in.	Factor by which to X area of chart sq. in.
1	20	11.6	48.9	.247
2	20	23.7	91.	.2604
3	20	34.	135.	.252
4	20	50.5	199.5	.2525
5	20	62.	245.	.2525
6	5	17.8	77.4	.2300
7	2	8.81	31.416	.2810

Striking out tests number 6 and 7 and averaging the remaining factors we have: Dynamometer Factor = 0.2528.

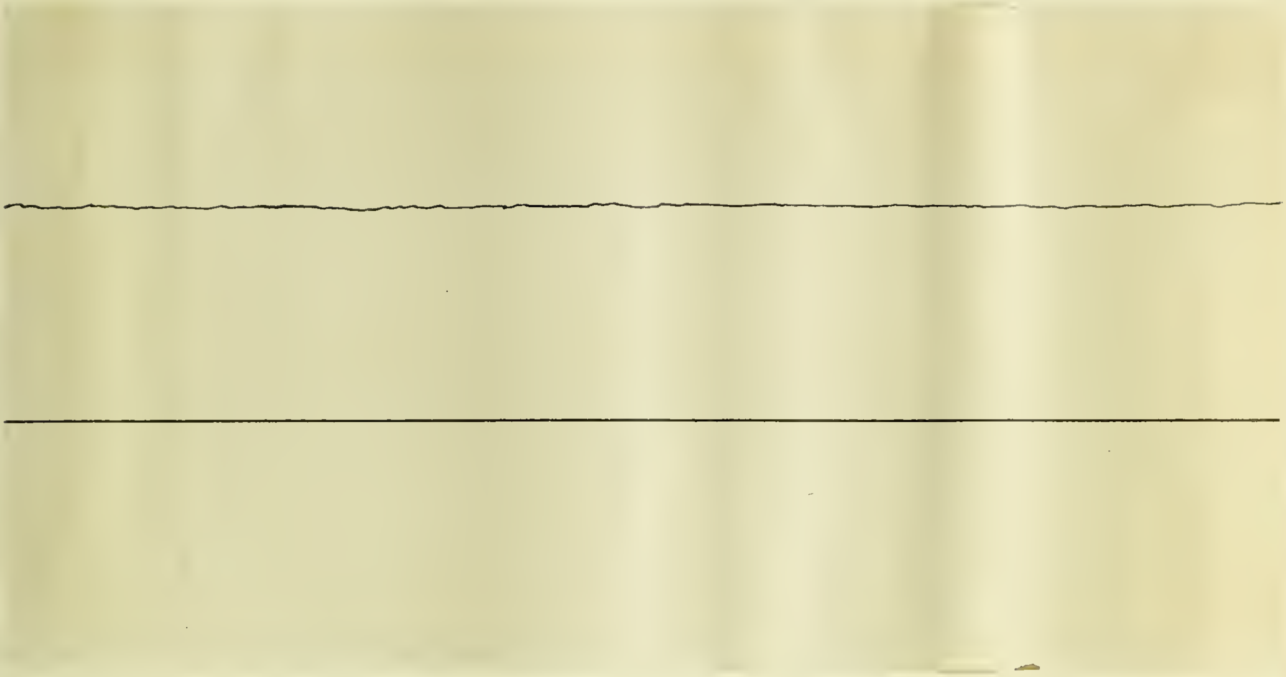
The following are cards taken during the above calibration.



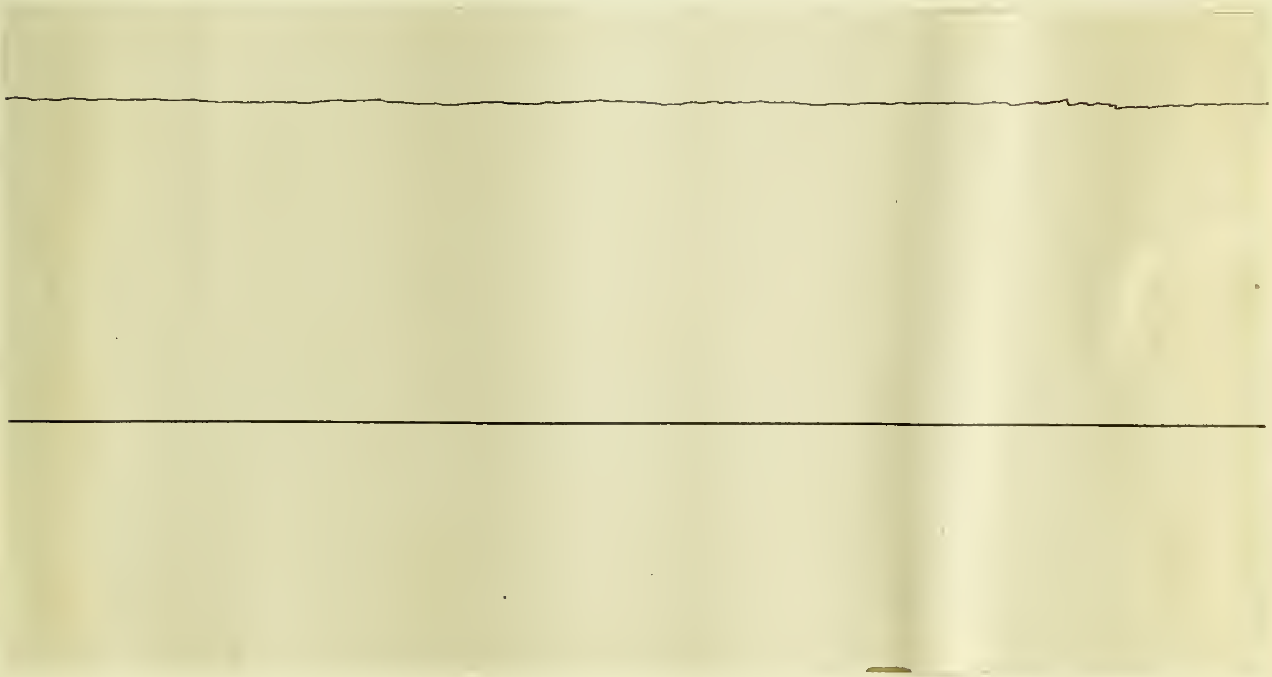
2nd Calibration, Wt. on Scales, 5#.



2nd Calibration, Wt. on Scales, 15#.



2nd Calibration, Wt. on Scales, 20#.



2nd Calibration, Wt. on Scales, 30#.

TEST ON LINE SHAFT IN MACHINE SHOPS AT THE UNIVERSITY OF ILLINOIS. URBANA. ILLINOIS.

The following is a test made on the line shaft on the north side of the machine shops at the University of Illinois.

Purpose of the test was to determine the power absorbed by friction in bearings, of shaft, and belt friction, or in other words, to determine the amount of power absorbed in transmitting power from the jack shaft to the machines on the north side of the above mentioned shops.

DESCRIPTION OF SHAFT AND CONDITIONS.

The shaft is 2 1/2 inches in diameter, approximately 220 feet long and runs at about 124 R.P.M. The shaft is in two sections and the coupling used is a friction clutch which is operated by a hand lever. The 1st section drives the machines in the machine shops, and the 2nd section the machinery in the Foundry and Forge shops. Length of 1st section 120 ft., 2nd section 100 ft. The entire shaft is supported by 22 bearings from overhead hangers, each bearing being 12" long, and having a bearing surface of 10" in length. The average distance between supports being 10 feet.

The dynamometer was placed upon the north bench, in line with the driving pulley on the jack shaft. This pulley was belted to the dynamometer by means of a 3" belt, a distance of approximately 25 feet.

The dynamometer was now belted to the line shaft by means of a 3" belt, thus the power, from the jack shaft was transmitted by the

dynamometer to the line shaft. The dynamometer was adjusted, as described on page 34, and the test made, the results being given in the following table.

It may be stated that the jack shaft was driven from a 20 H.P. Westing-house induction motor.

Tests 1 to 4 inclusive were made on Feb. 21st, 1903 P.M.

Tests 5 to 8 inclusive were made on Feb. 28th, 1903 P.M.

Dynamometer factor used .2528 as determined from last calibration. (see page 43).

$$\text{Total H.P.} = .2528 \quad \text{Area of chart in sq. in.}$$

$$\text{Average H.P.} = \frac{\text{Total H.P.}}{\text{Time in min.}}$$

RESULTS OF TESTS ON LINE SHAFT.

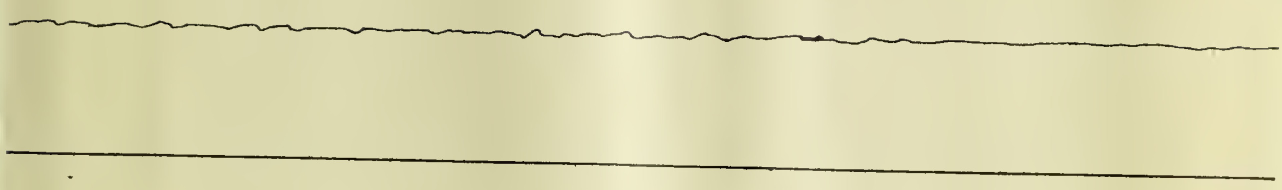
Test No.	Time in min,	Total area of Chart on sq. in.	Total H.P.	Ave. H.P.	H.P. per 100 ft of shaft.	Remarks.
1	5	100.6	25.5	5.1	2.3	Entire shaft all belts on.
2	10	88.9	22.5	2.25	1.87	1st section. " " "
3	10	87.2	22.1	2.21	1.84	" " " " "
4	10	89.1	22.58	2.25	1.87	" " " " "
5	10	82.2	20.8	2.08	1.73	" " " " "
6	20	360.	91.	4.55	2.06	Entire shaft " " "
7	25	188.8	47.9	1.01	.86	" " " " off.
8	30	145.6	36.8	1.23	1.02	1st section. " " "

The above line shaft has self oiling bearings.

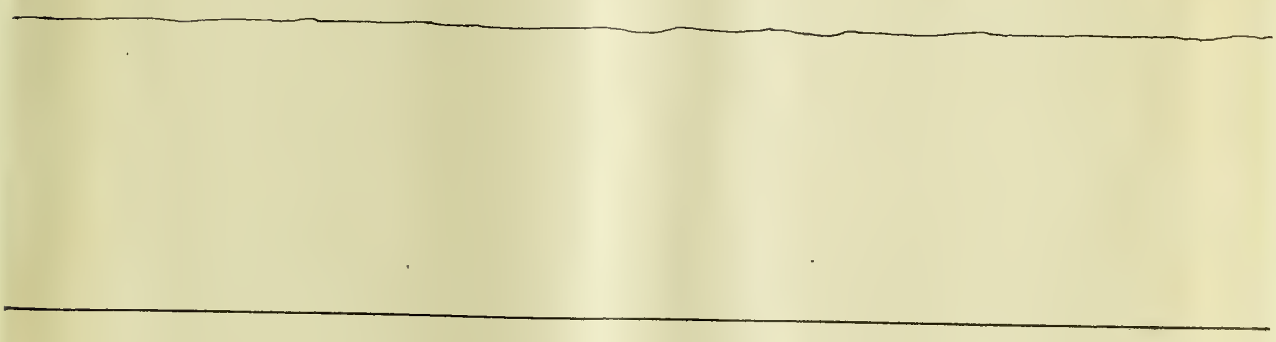
Summary: From the above it may be seen that about half the power is absorbed by each section of the shaft.

Also that the amount of power required to drive the shaft, with all the belts on, is double the amount of power required to drive the shaft with all the belts off.

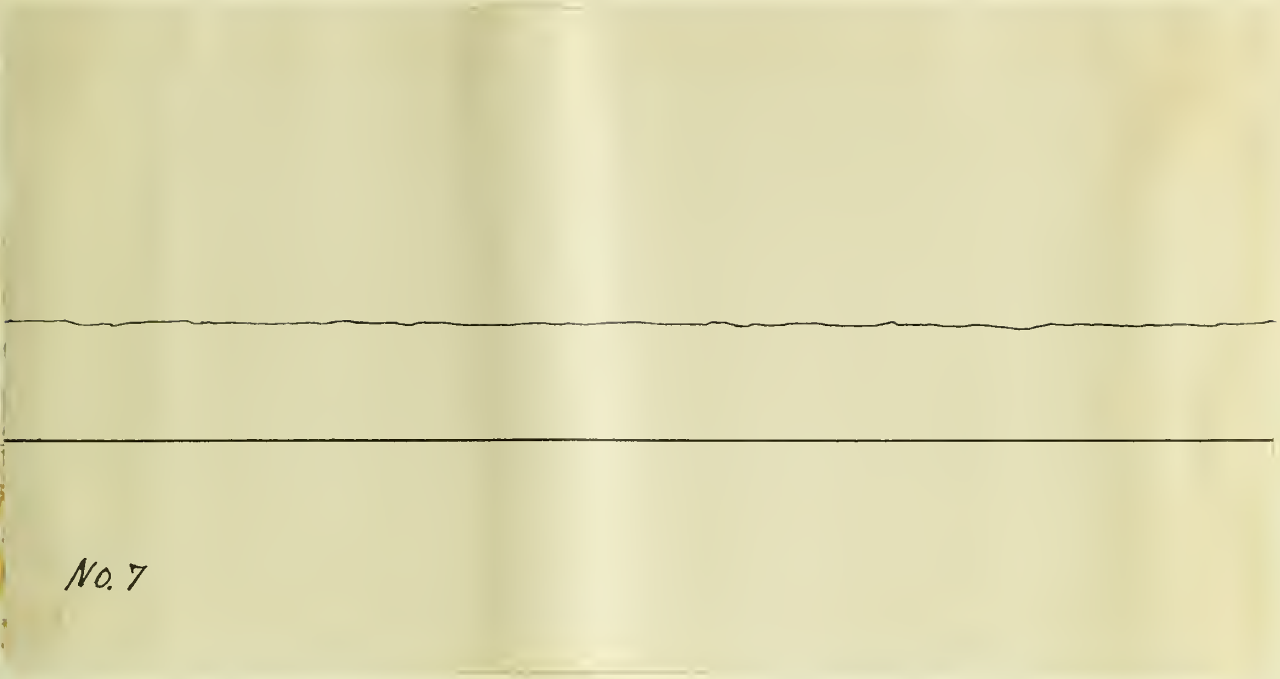
The following are cards taken during above test. The number on the card corresponds to the test number.



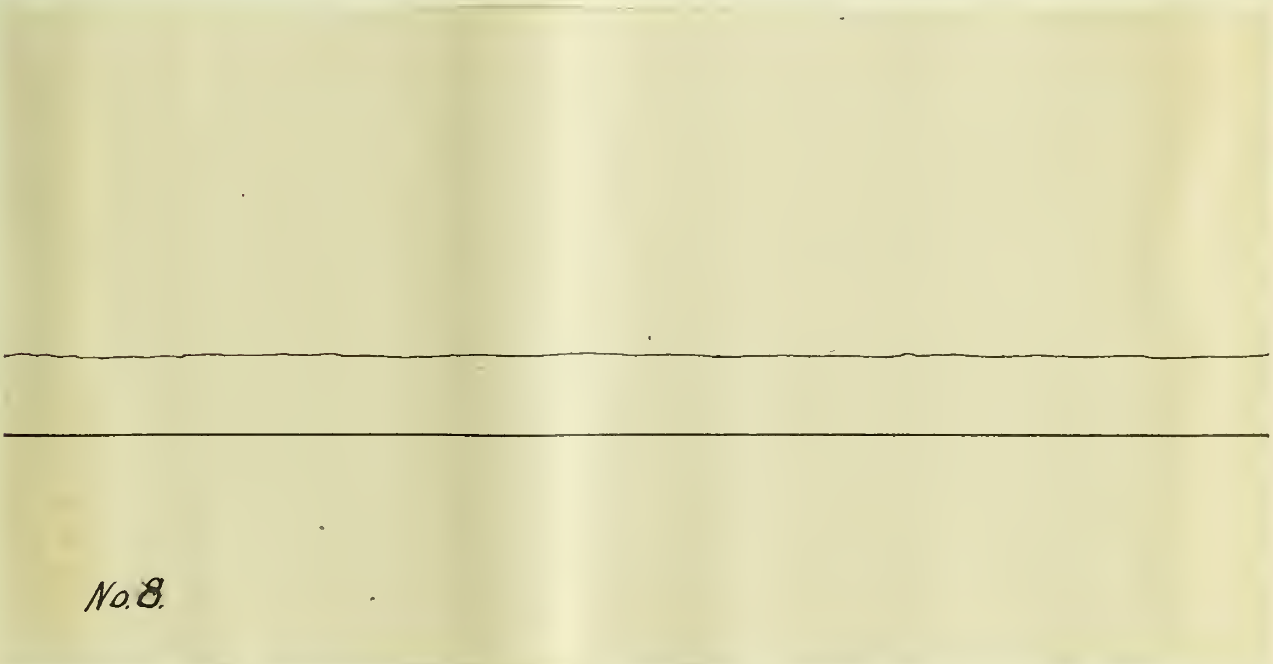
No. 4.



No. 6.



No. 7



No. 8.

EXPERIMENT ON A 26-INCH REED LATHE.

The above experiment was performed on May 2, P.M., 1903, in the machine shops of the University of Illinois, Urbana, Illinois.

The purpose of the experiment was to determine the amount of power required to remove machine steel, by turning in a lathe. The dynamometer was belted in between the line shaft and counter shaft of the lathe; thus giving the entire power which was necessary to drive the counter shaft and the lathe.

The power required to remove the metal was obtained by the method of differences; that is, a card was taken with the lathe running light, at the same speed and under same conditions as when tool was cutting; then a card following with the tool in operation. The difference in the power used is evidently due to the action of the tool.

Manner of Conducting the Experiment.-

The machine was arranged as described above. The piece of machine steel, 2 1/2" in diameter and 30" long, was accurately centered and mounted in the lathe in the usual manner. The tool was sharpened before each cut, and the conditions surrounding the cutting edge of the tool were kept constant throughout the experiments. The tool and lathe were now adjusted so that the piece would be turned down to 2" in diameter. After this adjustment the tool was withdrawn and a card was taken with the lathe running light.

The cut which reduced the piece from 2 1/2" to 2" was now made, and the card taken, together with the R.P.M. of the lathe. The duration of the experiment was also recorded. The chips, which were turned off were caught in a sheet and accurately weighed.

On page 54, is shown a part of the cards taken during the experiments. The No. of the card corresponds to the No. of the experiment.

In the following table the cutting action only is recorded.

MAY 2, 1903, P.M.

H.P. REQUIRED TO REMOVE METAL IN A 26-INCH REED LATHE.

MACHINE STEEL.

KIND OF CUT. - REDUCING OR ROUGHING CUT.

No. of Ex.	Feed	Av. cutting Speed in Ft. per min.	Av. breadth of cut inches.	Av. H.P. required to remove metal	Av. lb. of metal turned off per hour.	Value of Constant C.	Tool Used
1	2 1/2"- 2"	15.4	.0353	1.106	25.1	.0432	Hog nose.
2	2"- 1 1/2"	17.2	.0422	1.009	23.64	.0426	Hog nose.
3	1 1/2"- 1 11/32"	18.9	.0375	.485	11.76	.0414	Round nose.

Average .0426

The value of C is determined by the relation between the weights of chips removed per hour and the horse power used, such that

$$H P = C W$$

where

C = constant,

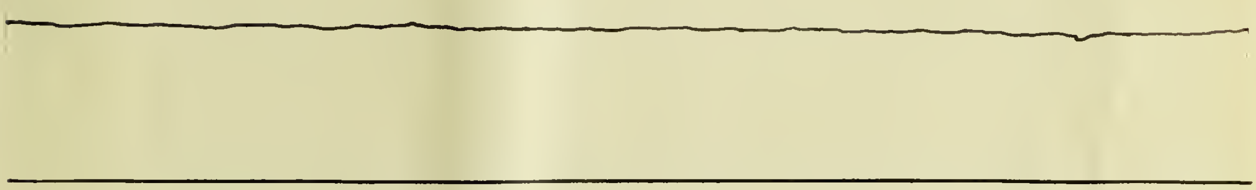
W = Wt. of metal removed, per hour.

Comparing these results with those of Hartig, R.H. Smith and J.D. Hoffman, given on page 26.

We have;

	Steel Value of C.
From above Exp. and table	.0426
J.D. Hoffman	.039
Hartig	.047
R.H. Smith	.042

No. 1



No. 3